SEQUENCE IN WELDED SHIP DESIGN AND CONSTRUCTION.

by

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It was essential for ship builders to revise their thinking, away from the old conventional methods of shipbuilding, whereby each piece of the vessel was assembled on the building ways, to the modern concept of final assembly of prefabricated units or sections. The recent war, with its unprecedented demand for ships, afforded added impetus to this concept. Some of the early experiences of shipyards, accustomed to riveted construction, were unfortunate when they attempted all welded construction. Warpage, distortion, dimensional instability, and

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serious fractures were the common ailments.

As an aid in visualizing the modern concept of ship construction, the following outline of the procedure used in the construction of a typical cargo vessel will be helpful:-

1. Planning and design for welded construction.
2. Fabrication of plating and framing by flame cutting and beveling of edges where necessary. (to be done in the shops.)
3. Construction of sub-assemblies of as large a size as the yard facilities will permit. (to be done on slabs and under cover, when possible)
4. Erection of these sub-assemblies into sections.
5. Final assembly of the sections on the building ways.

With the above outline in mind, it is possible to imagine the desirability of a well-planned sequence of operations to ensure a smooth flow of materials, elimination of useless work, and the logical erection of the vessel. A little less obvious, but perhaps even more important from the standpoint of the seaworthiness of the completed ship, is the elimination of the previously mentioned troubles by proper welding and erection sequence. It is the purpose of this paper to present a discussion of the reasoning behind the sequence and to show how it is applied in the yards to build stress-free, dimensionally accurate, all-welded ships. The type of ship discussed will be limited to cargo ships, but the principles could be applied to any welded vessel. It is desired to point out that an all-welded ship is monolithic in character, as contrasted with riveted ships. As a

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consequence, welded ships are considerably stiffer, an important consideration in seagoing qualities.

Distortion:-

Distortion, the twisting or bending of a structure out of the regular or intended shape, is the greatest obstacle to overcome in welded ship construction. Residual stress, locked-in stress, and warping will be essentially eliminated if the ship is built with a minimum of distortion. When a ship is welded, there is a tendency for the bow and stern to lift off the blocks, and for the bilges to rise. There have been some extreme cases of this effect. Distortion also causes poor underwater lines, thus seriously affecting the ship's handling characteristics. Another bad effect is departure from the specified dimensions of the ship, ie. length and beam.

The residual stresses resulting from the ship being built where distortions are present, or where distortions have been forcibly corrected, are often quite high and constitute a serious pre-loading of joints and structure.

The principal cause of distortion is shrinkage due to welding, although there are other causes such as:-

1. storage and handling distortions.
2. flame cutting ~~and~~ shrinkage.
3. improper fitting.
4. unequal expansion due to the sun's rays or atmospheric conditions.
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4. Unequal expansion due to the sun's rays or atmospheric conditions.
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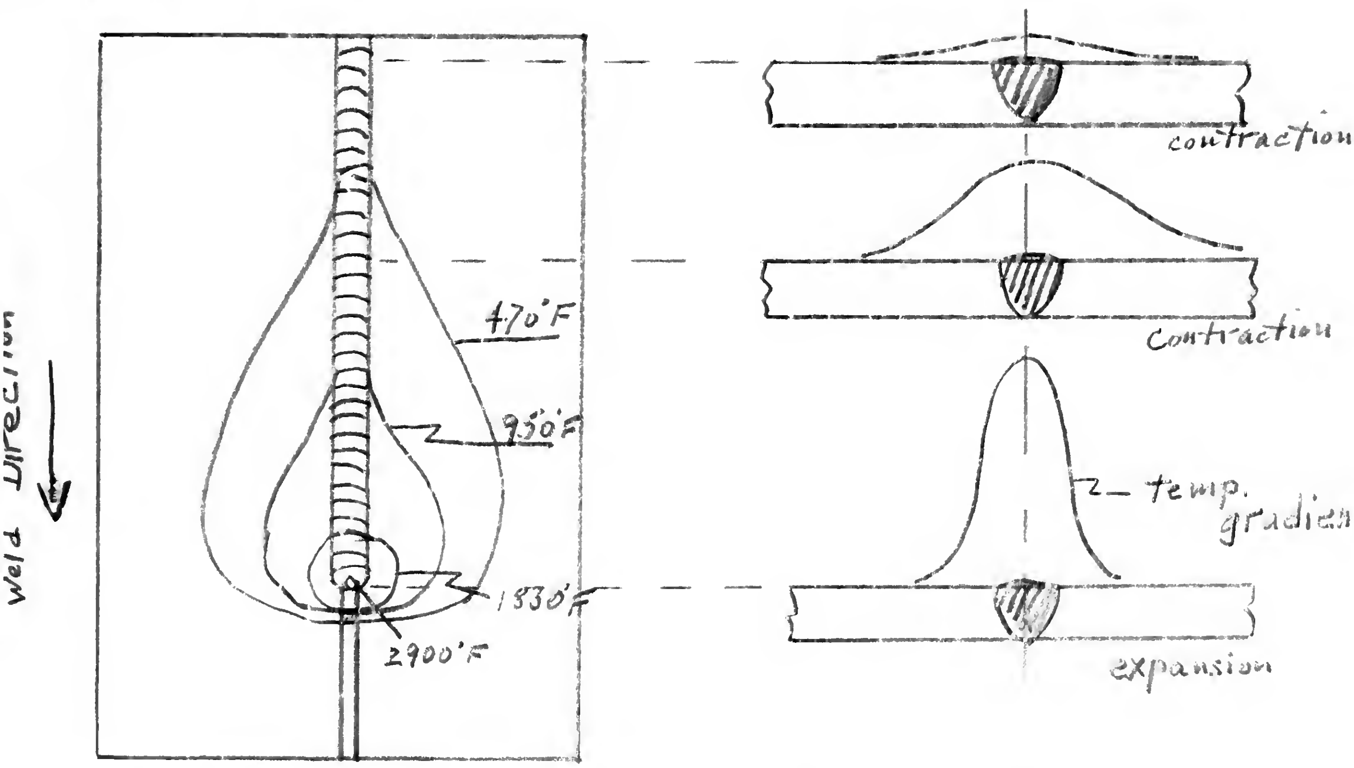
Welding and erection sequences constitute the proper means to correct distortion, although it is possible to make force fits, heat to expand a local area and then quench, peening, and other even less desirable methods. To understand how distortion comes about, and why sequence is so important in eliminating it, the following section will go into the effects of expansion and contraction in the welding process.

Expansion and Contraction:-

When metals are heated they expand and when cooled they contract. Not only the weld metal itself, but also the base metal, which is being joined, follows this law. An illustration of the temperature gradients to be expected as a bead is laid, follows:-



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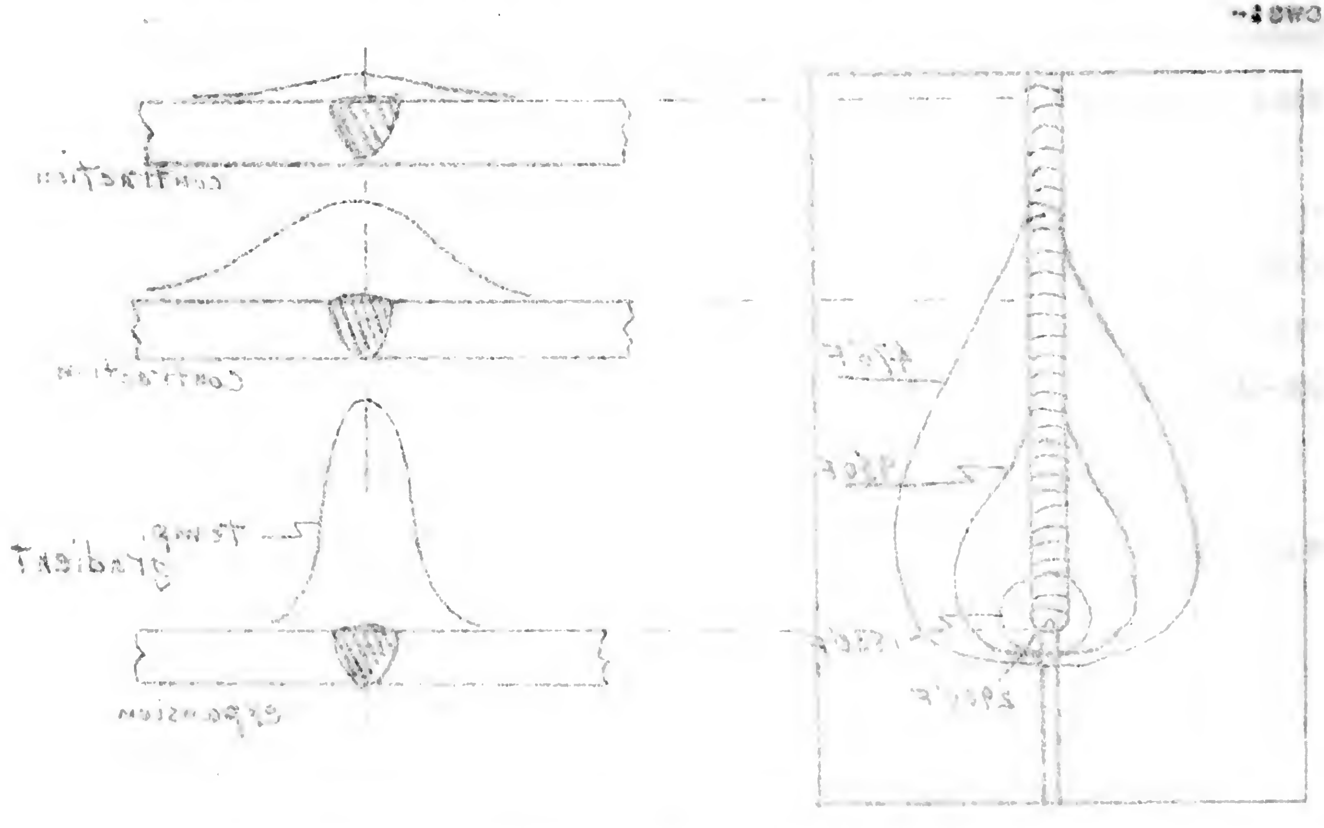

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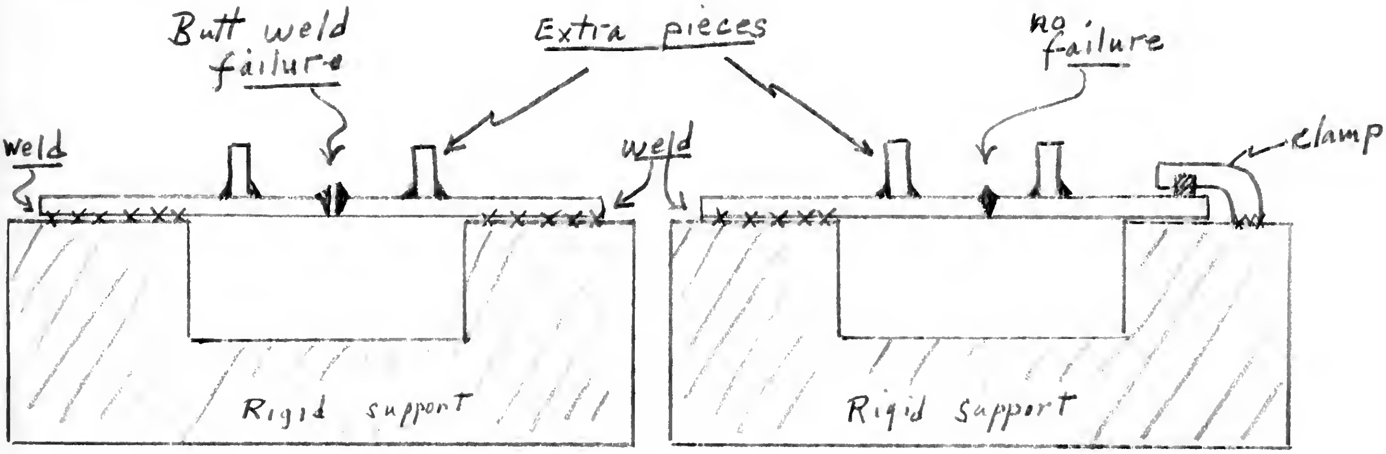
is easy to see what would be the case if the plates were restrained during this heating and cooling ~~period~~ cycle. The final result would be an overall contraction in the plane of the plate, perpendicular to the bead, due to the contraction of the weld metal, whose expansion on heating was resisted by the restrained plates, thus setting up a condition of residual stress, or else resulting in distortion as a means of relieving the stress. The following sketches show the results of unrestrained and restrained welding:-



Cases #1 and #2.   Case #3.

In case #1, two members were welded while both were entirely restrained, resulting in fracture of the butt weld due to the weld contraction. In case#2, the butt weld held, and then two extra members were welded onto the pieces, as noted, resulting in fracture of the butt weld. In case #3, one end was firmly anchored by welding, while the other end was clamped in such a manner as to allow some freedom of movement. The butt weld did not fail.

The above reasoning leads to a fundamental rule: Leave one end of a member or structure free to contract towards the

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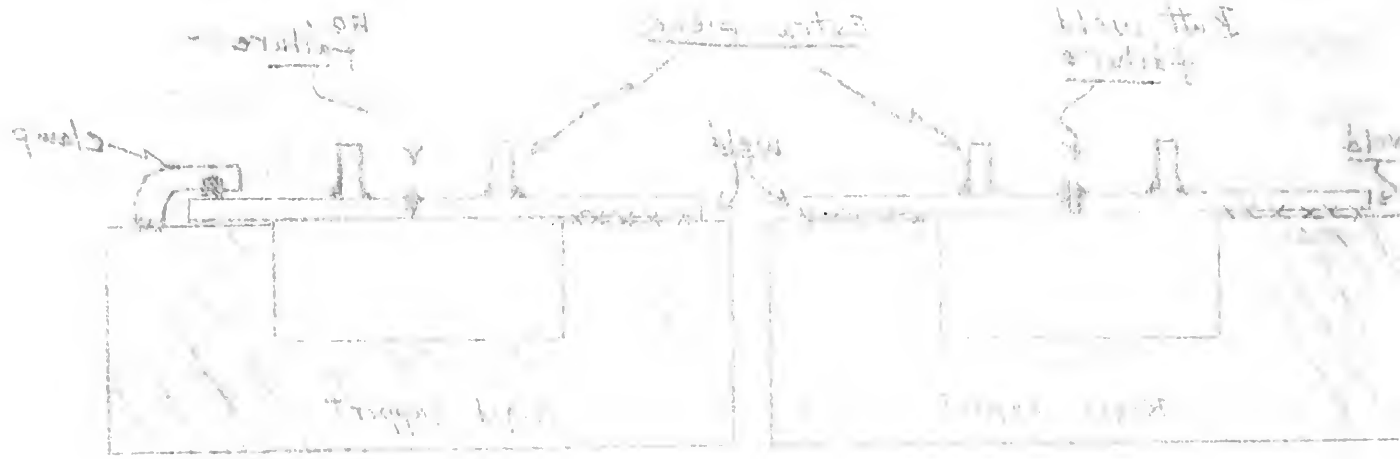

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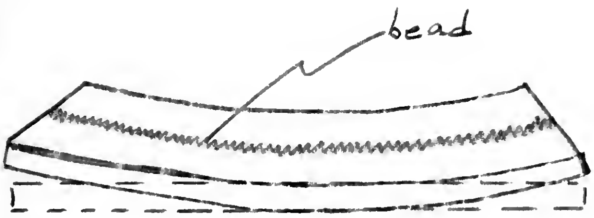
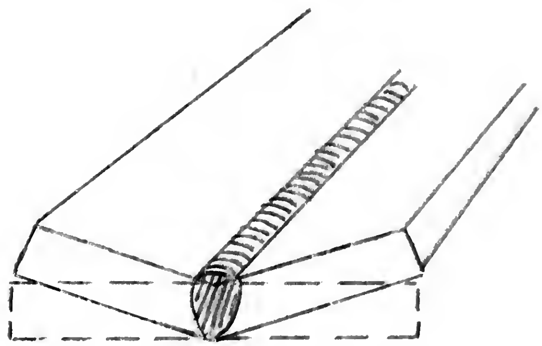
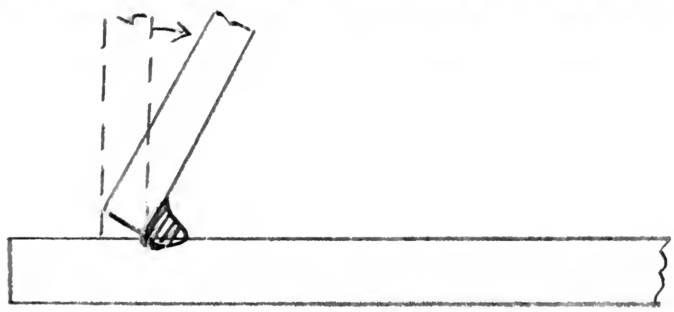
point of welding. This rule must be considered in design and planning as well as by the welders and shipfitters.

Warping is primarily caused by the heating effects due to welding. When a bead is laid on a flat plate, the plate will warp as shown below, if it is not restrained or not heavy enough to resist the contraction forces:-





Another example of warping is that caused in welding a Tee joint:-



When two plates with an opening between them are welded, the plates will draw together as the welding progresses, and the amount will depend on the speed of welding and on the type of electrodes. Slow rate of travel and bare electrodes will cause greater drawing together. With shielded arc electrodes and very rapid travel, the plates may even separate on welding but will still come together when cooled. The initial separation is caused by less total heat input and the protective coating, over the bead, acting somewhat

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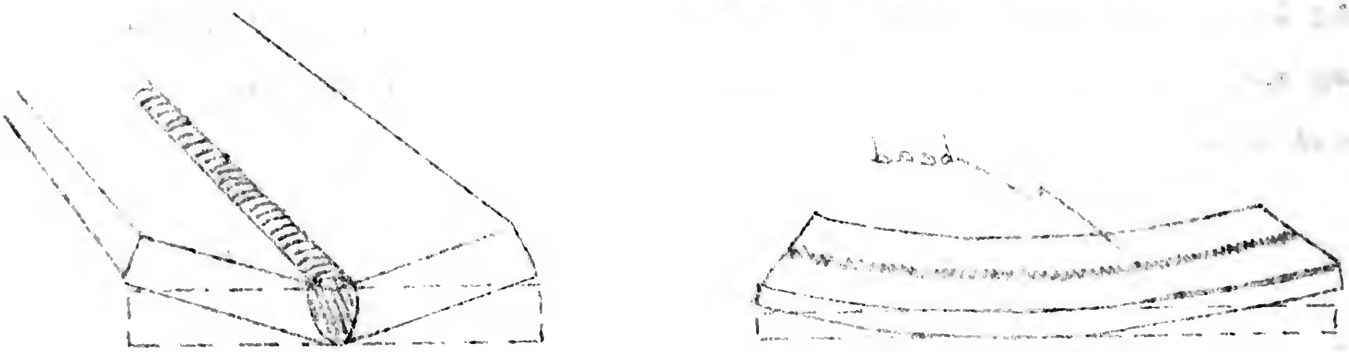

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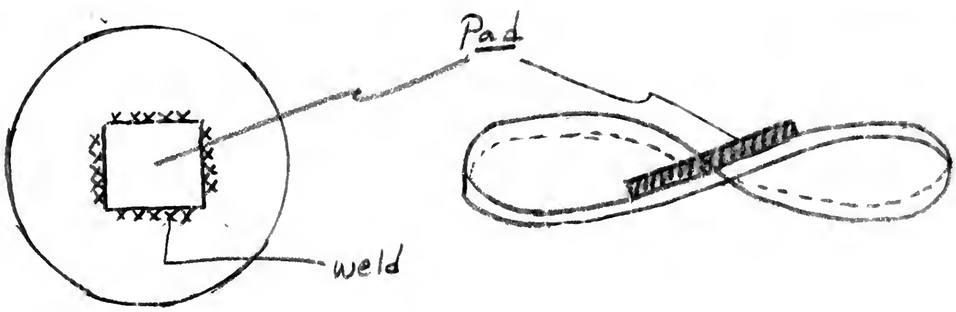
as an insulator. If the seam is long, tack welds are desirable to maintain some degree of correct positioning of the plates. Further, if the plates are beveled for manual welding, there will be a tendency for the plates to bend upwards around the weld bead. The amount of this warping is directly dependent on the number of passes, which indicates that it is desirable to complete the weld with the minimum number of passes and the minimum amount of weld metal. Another frequently encountered case of warpage is when a pad is welded to a circular disc. This is illustrated below:-



If, however, the circular plate had been clamped or weighted in such a manner as to partially restrain movement in a vertical direction, then the plate would have been flat when the weld was completed.

The above illustrations of tack welding and clamping give a second fundamental rule: Warpage may be prevented through partial restraint by clamping or weighting the members down. This rule is particularly applicable to the fabrication of the subassemblies on the flats or slabs, where jigs, dogs, and weights are available. When applied to the main erection of large sections or to the final assembly, the use of strongbacks, and other means of bracing, accomplish much the same result.

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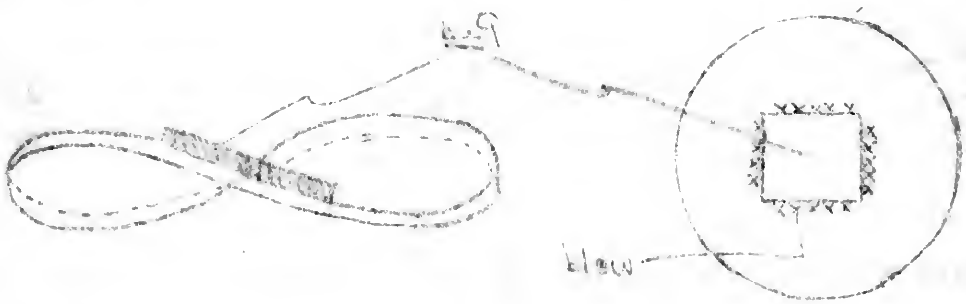

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The use of jigs and other means of restraining warpage will most likely leave large residual stresses within the fabricated part. There are three possibilities concerning the relief of these stresses:-

a. The part will warp when removed from the jig.

b. The weld will crack.

c. The weld or adjacent plate will yield plastically.

Residual stresses may remain in the part only up to the yield point without some plastic deformation occuring. It should be noted that with the mild steels (.20C on the average) used in ship building, unless the restraint is severe, the plate or bead will yield plastically to relieve severe residual stress, without suffering any loss in ultimate strength upon future reloading.

It has been found that residual stresses remaining below the yield point will not be appreciably relieved in service. On the other hand, it has been determined, in general, that residual stresses do not contribute appreciably to the failures of welded ships at sea, unless there is a localized bad combination of residual stresses, some form of notch present, and severe loading. In passing, it might be well to note that the primary cause of the failures of welded ships is brittleness of the steel, induced by the multi-axial stress system acting at the base of the notch. The notch may be one caused by poor geometrical design of the vessel, (square sheer strake cut-outs, for example) or by poor workmanship (defects in the weld or incomplete penetration). The above is aggravated by notch-sensitive steel, especially at low temperatures.

Development of Welding Sequence to Control Shrinkage:-

Since it has been shown that the major contribution to distortion is weld shrinkage, this section will deal with the means by which shrinkage is kept under control. The basic ideas of welding sequence will be developed in the discussion.

The amount of weld shrinkage is governed by several factors:-

1. The amount of heat that a welder uses for a given size rod and weld.
2. The rate of travel along the weld.
3. The root opening and the weld size.

The most efficient welds are made by using, (1), as large a size electrode as possible, (2), high current, and (3), fast travel. All these factors signify that less shrinkage will be had, due to less heat input into the weld. This method of welding will also result in deeper penetration, with a consequently greater heat penetration to the reverse side of the weld, resulting in less warping, due to the thermal gradient. It is to be noted that the major shrinkage in manual welding is at right angles to the direction of welding. The shrinkage, in the direction of welding, is negligable.

Some of the ways in which shrinkage can be controlled or counteracted:-

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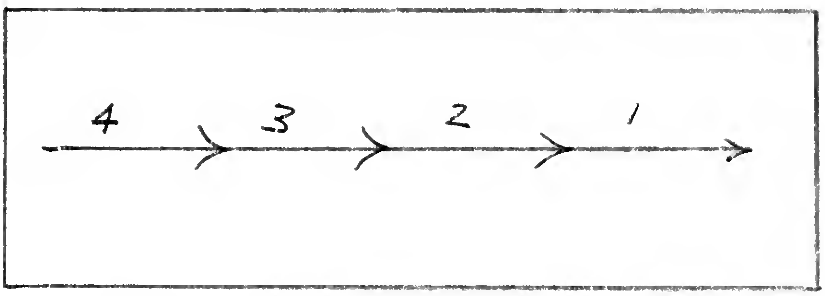
4. use of partial restraints.
5. keeping the welding evenly balanced both vertically and horizontally.
6. by various post-welding treatments, such as peening or annealing.
7. erection by sub-assemblies.

Only those ways which relate to sequence will be further discussed.

The wandering procedure is the running of short bead increments at random throughout the structure. This spreads the heat over the entire structure and lowers the general level of heat. It is interesting to note that there may be considerable rise in the temperature of a structure and consequent distortion if there are too many welders working on it, especially in a concentrated locality.

Back-step procedure is very effective and is illustrated by the following sketch:-



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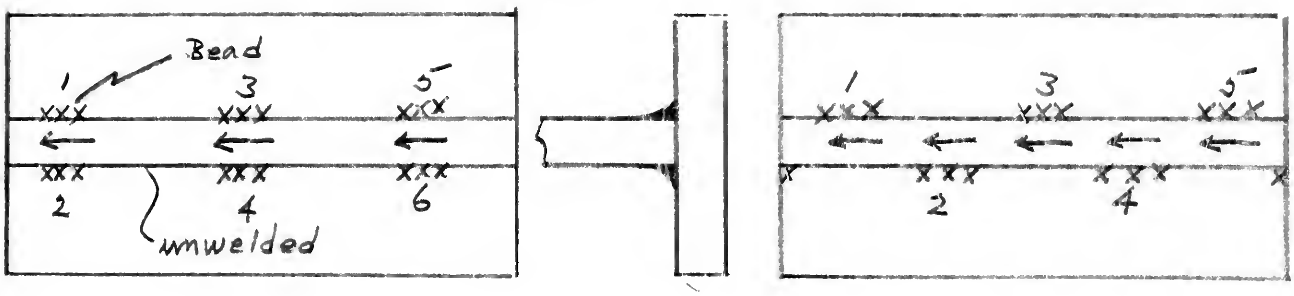

The important idea so far noted in regard to sequence, is the reduction of weld bead shrinkage effects to reduce distortion.

The next point is keeping the welding evenly balanced out on either side of a structure when welding. By evenly balanced it is meant using welders on either side of the structure, performing identical operations simultaniously. This is particularly important in long structures, in which the wandering sequence may be used, or else the welding should start at center and progress outwards. This will become more apparent when applications are discussed later on.

The erection by sub-assembly is a potent means of combatting shrinkage troubles. The sub-assemblies are made up of pre-fabricated parts, which have already contracted when each was welded, and thus their individual contractions will not af-

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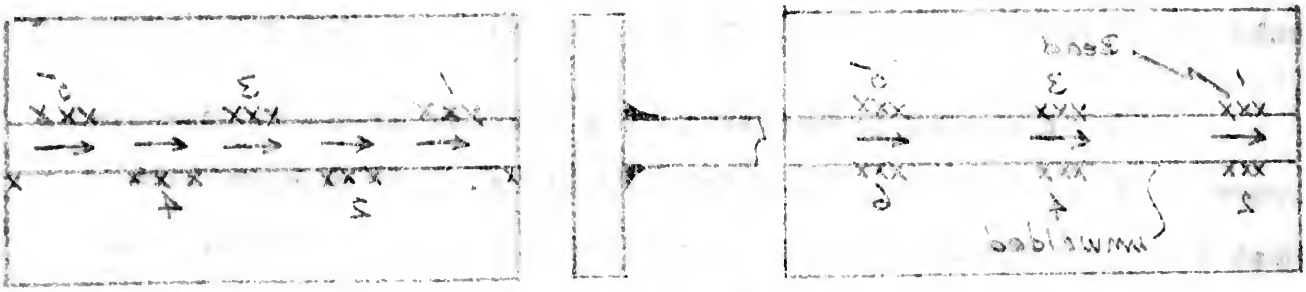

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In summary, the fundamentals of welding sequence are:-

1. Plan to reduce the heat input to a minimum and to distribute the heat throughout the structure, when considered as a whole. This involves wandering, skip welding, or backstep.
2. Balance out the welding from side to side of a structure.
3. Start welding a structure, such as the final erection of the sub-assemblies, from the bottom center and work outwards and upwards, leaving the ends free until the last.

Design and Planning for Sequence:-

It is a recognized fact that erection and welding sequences are not inseparable, and, therefore, in designing and planning they should be coordinated. Draftsmen should be familiar with proper welding practices as well as structure design. To build a sound welded ship, which embodies all the advantages of welded construction, the welding and erection sequences must be worked out in detail and presented in a logical manner to the supervisory force of the shipyard. There is no such thing as too much detail in stating the sequences.

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if the total distortion and residual stresses in the hull are to be kept at a minimum. Even with recognized good design and planning, there is an over-all allowance made for shrinkage which, in a cargo vessel, amounts to 1 inch / 100 feet of length and 1 inch from the designed molded beam. The deviation from the true measurements is checked from time to time by surveying, and, if the deviation is too large, steps are immediately taken to remedy it.

A very important point in planning a sequence is to analyze what influence warpings will have on the hull as a whole, and then to divide the hull up into bays which are to be welded in a sequence, such that the stresses and warping arising will counteract each other. The sequence of welding must also be planned such that the members have freedom of motion along the designed lines of the ship so as to minimize distortions from the desired under-water form. As an aid to the above, one shipyard has developed the method of making a transparent plastic model of the ship, to exact scale. The model is built up in the desired sections and sub-assemblies, which can be disassembled for detailed study, later. The model is used for final planning of sequences and for instructing the supervisory personnel. As a sidelight of this model idea, it is possible to very greatly increase the amount of automatic welding possible to perform on the hull, due to the ease with which favorable situations for it can be visualized. The same reasoning applies to the developement of jigs and fixtures allowing a maximum of down-hand welding. These points add greatly to the economy and increase the seaworthiness of the vessel.

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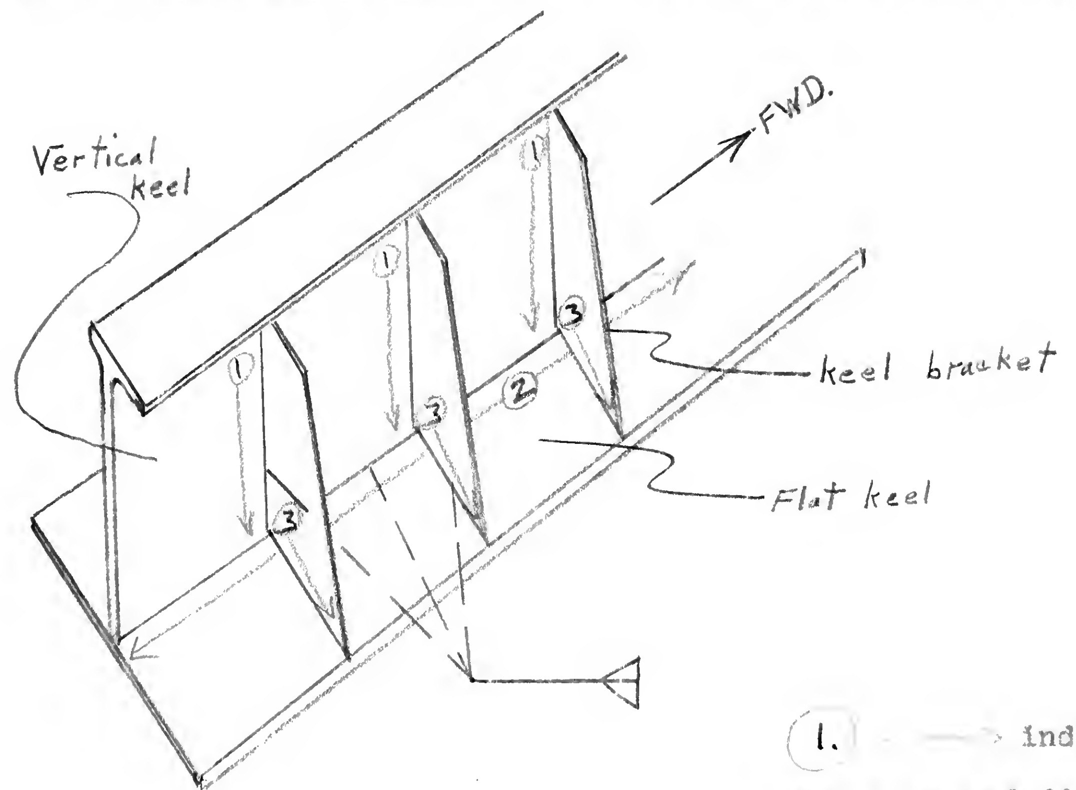
Applications of Welding and Erection Sequence:-

As can be seen from this paper, the idea of sequence grew up as a result of practicAl experience and empirical knowledge. Soon, however, the scientific reasoning of welding engineers arrived at the basic fundamentals previously noted. It is of interest to see how these principles are applied in one or two actual cases.

For the first case, a simple sub-assembly of a longitudinal keel section will be taken. The following sketches will illustrate the fundamentals as applied to this type of sub-assembly:-



1. ——> indicates sequence and direction of laying the bead.

Back-step all beads.

1. Weld opposite side brackets simultaneously.

Tack down as required.

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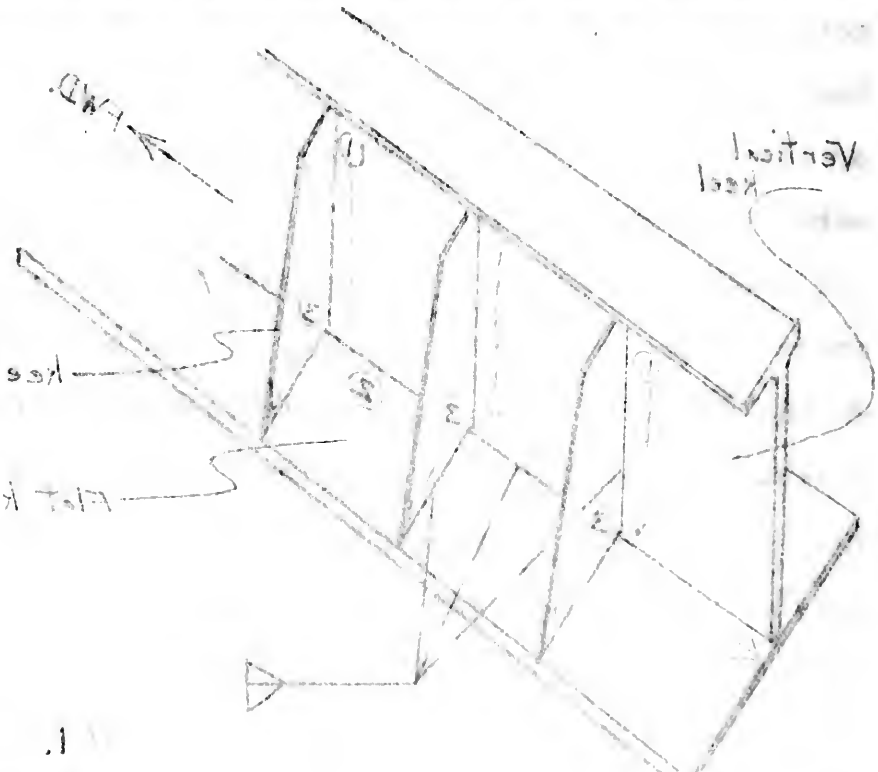


1. indicates sequence and direction of laying the bead.

Back-step all beads.

1. Weld opposite side brackets simultaneously.
Tack down as required.

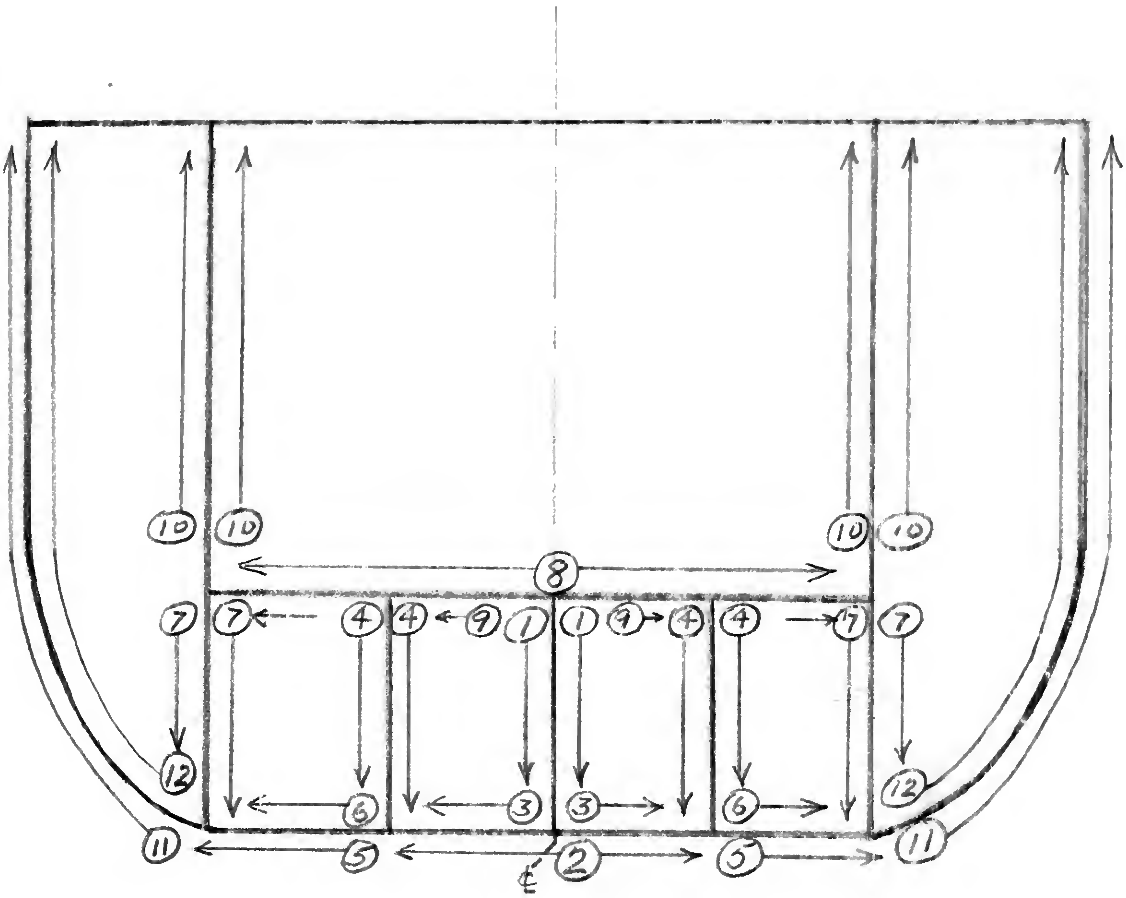
2) Start welding at center of keel sections Weld fore and aft short lengths alternately. Weld port and starboard simultaneously. Do not tack down more than one bracket ahead of welding.

3) Weld opposite side brackets simultaneously.

Welding of the brackets to both the vertical and the flat keels must be kept evenly balanced, and the heating of the vertical keel must be evenly distributed from top to bottom to maintain alignment. This latter is done by the use of back-step welding. Care must be exercised in tacking down too far ahead of the point where welding is being done or else warpage will result, due to the uneven distribution of stresses. Despite such care, it is often necessary to bow down a keel sub-assembly to offset contraction between top and bottom of the keel assembly.

The second example will illustrate one sequence, in which two sections are joined together on the building ways. The sequence presented here is typical of the hull work done on the building ways. It is to be remembered in this case that the bulkhead section pictured is the boundary between two prefabricated hull sections and is thus in a vertical position, which precludes the use of an automatic welding machine.

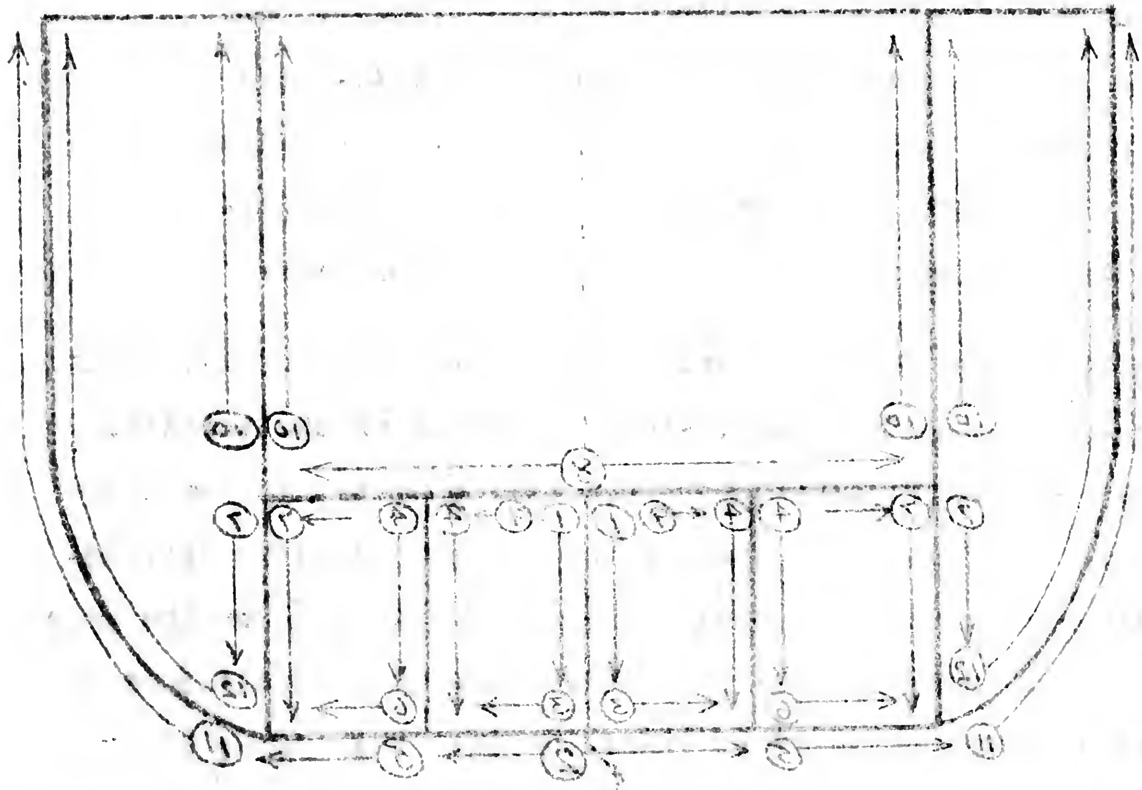
(see next page for sketch.)



All the above welding is to be done by the back-step method and by a pair of welders, working one on each side of the centerline. Note that the sequence is started at the keel. All the interior joints are made prior to welding the sides of the shell. It is important that all the internal welding in each section should be completed prior to the final assembly.

In the erection and welding of vessels of longitudinal construction, rather than the sectional construction noted in the second example above, the sequence is as follows;-

1. placing and welding of the keel assembles on the keel blocks.
2. erection of the bottom shell with the butts of the plates being welded starting from



All the above welding is to be done by the back-step method and by a pair of welders, working one on each side of the centerline. Note that the sequence is started at the keel. All the interior joints are made prior to welding the sides of the shell. It is important that all the internal welding in each section should be completed prior to the final assembly.

In the erection and welding of vessels of longitudinal construction, rather than the sectional construction noted in the second example above, the sequence is as follows:-

1. placing and welding of the keel assemblies on the keel blocks.
2. erection of the bottom shell with the butts of the plates being welded starting from

amidships and working fore and aft, while the the longitudinal seams of the plates are restrained from getting out of alignment, by use of bolts or spacers.

3. erection of longitudinals and bulkheads (subassemblies).
4. erection and welding of the upper shell plating and main deck, taking similar precautions as in weldáng the bottom shell.
5. internal decks are then welded all around, after the shrinkage has taken place in the shell.

It should be pointed out that longitudinals, including decks, should never be restrained from contracting by tacking or welding them before the full transverse shrinkage has taken place. Sequence is extremely important in this effect. If there is a keel rise, there is internal or locked-up stress which, if detected in time, can be corrected by changing the welding sequence from a straight side to side band type of sequence to an angle in relation to the keel, by which is meant that lower levels are welded first (in going away from amidships) which will tend to draw the bow or stern down. The above discussion of a longitudinal designed ship applies more to a destroyer type vessel, in which the length to beam ratio is large.

Final Remarks:-

The importance of welding and erection sequence has been discussed with the particular aim of showing the scientific rea-

soning upon which its development is based and to present some idea of its application in modern shipbuilding. The principles of step-back and starting from the center and working outboard, are utilized in the final assembly of the ship, as well as in the welding of its components. Without the knowledge of sequence, ship construction on semi-assembly line methods would be out of the question.

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Bibliography

1. Welding Handbook, AWS,(1942).

2. Procedure Handbook of Arc Welding Design and Practise, Lincoln Electric Company, Cleveland,Ohio, (1940).

3. The Design and Methods of Construction of Welded Steel Merchant Vessels, Ship Structure Committee,US Navy, 15 July 1946.

4. M.Q. Cellers, Erection and Welding Sequence as Applied to Welded Steel Hulls, Welding Journal,(1944) 23,(3)205.

5. A.E. Wallen, Sectional Ship Erection Welding Sequence, Welding Journal, (1944),23, (7),622.

6. J. Turnbull, Structural Design of Welded Hulls, Engineering, (1943),155, #4038, June 4, p 447.

7. O. Overgaard, Sequence in Welding of Ships, Welding Journal,(1944), 23, (5), 423.

8. A. Amerikian, Some Problems of Welding Design and Fabrication of Steel Floating Drydocks, Welding Journal, (1946),25, (10), 929.

9. M. Forman, Flame Cutting Plates for Welded Ships, Welding Engineer, (1947), 32, (3), 53.

10. Production Planning for Welded Ship Construction with Paper and Plastic, Welding Journal,(1945) 24,(4) 347.

11. W.B. Bowen, Planning for Production Welding and Cutting in a Modern Shipyard, Welding Journal, (1943) 22 (11) 904.

12. W. Sparagen and M.A. Cordovi, Peening- Its Effect on Relief of Residual Stress, Distortion, and Mechanical Properties of Welds, Welding Journal, (1944) 23, (3), 121s.

13. M. Forman, Organized Fitting and Welding in Shipbuilding, Welding Journal, (1945) 24, (4), 351.

14. Fleet-Welding, Lincoln Electic Company, Cleveland,Ohio, Bulle 440.

15. Report on Thermal Stresses and Shrinkage in Welded Ship Construction, AWS, New York, 1941.

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